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Comparative Study of Fuel Cell Applications and Future Plant Conservation Applications

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Abstract

The Kyoto agreement showed the need to reduce the emissions of greenhouse gases and, in consequence, the interest in efficient systems were highlighted, like fuel cells, due to their low environmental impact. A fuel cell that generates electricity through a chemical reaction used can employ hydrogen, methane gas or liquids such as methanol. Several technologies are used depending on the operating temperature, catalyst and electrolyte membrane, while the analysis of the most efficient techniques depends on applications, power generation systems and efficiency in each case. Technologies do not have the same applications, but that's more suitable for mobile and stationary applications. In the present paper, the economic and environmental cost of this technology will be analyzed.

Keywords

Hydrogen Fuel Cell; Alkaline Fuel Cell; Exothermic Reaction

Introduction

In previous research works, the state-of-the-art of fuel cells systems were analysed and the operation of a hybrid fuel cells plant in a ''typical hospital'' was simulated to define how it could optimize the hospitals energetic requirements (Bizzarri and Morini, 2004).

Hospitals and sanitary structures are normally characterized by considerable energy demands not often suitable with resolute energy retrofit strategies.

A fuel cell is an electrochemical device which converts energy similarly to a battery, but it differs from the latter in that it is designed to allow for continuous replenishment of the reactants consumed, i.e. electricity is produced from an external source of fuel and oxygen in contrast to the limited capacity of energy storage that a battery possesses. Moreover, the electrodes in a battery according to react and change as load is, however, in a fuel cell electrode catalyst and are relatively stable.

Typical reagents used in a fuel cell are hydrogen, on the anode side, and oxygen, on the cathode side (in the case of a hydrogen fuel cell). Furthermore, batteries consume solid reactants and once exhausted, they should be recharged with electricity.

Both the considerable primary energy savings and the pollutant emissions reduction, achieved by upgrading conventional systems to a fuel cell hybrid plant, have the potential to prompt national boards to support their business development, as long as they achieve a consolidated market penetration.

Technology

These cells may employ various types of H_2 hydrogen rich fuels, such as natural gas, diesel, biogas, alcohols or propane. The use of hydrocarbons generates derivatives such as CO and CO_2, but given the high efficiency of these devices (compared to combustion engines), for equivalent amounts of electricity produced, CO_2 emissions can be reduced by half or less, with the corresponding environmental benefit. They operate at different pressures and temperatures, ranging from atmospheric pressure up to 100 times this one, and from 20°C to 1000°C respectively (Hughes W.L., 2001).

On the anode side, hydrogen that reaches anode catalyst dissociates into protons and electrons. The protons are conducted through the membrane to the cathode, but the electrons are forced to move through an external circuit producing energy (since the membrane is electrically isolated).

The voltage is about 1,229 V (Winkler W., 2003; Chase M. W., 1985; Atkins P.W., 1986; Carnot S., 1960; Erns W.D., 2001; U.S. Departmnent of Energy, 2002) or below, with a current density of 2000 A/m^2. Therefore, it is necessary to groupe basic units to achieve efficiencies up to 60%, always referred to as the calorific value of the fuel used.

The main reaction in the fuel cell is the inverse of the

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electrolysis of water, i.e. it is the combination of hydrogen and oxygen to form water and electricity (Farooque and Maru, 2001) The reaction is:

$$H_2(gas) + \tfrac{1}{2}O_2(gas) \rightarrow H_2O + electric\_energy \qquad (2.1)$$

Thus the anode reaction is:

$$H_2 \rightarrow 2\mathrm{H}^+ + 2e^- \qquad (2.2)$$

And at the cathode it is:

$$\tfrac{1}{2}O_2 + 2\mathrm{H}^+ + 2e^- \rightarrow H_2O \qquad (2.3)$$

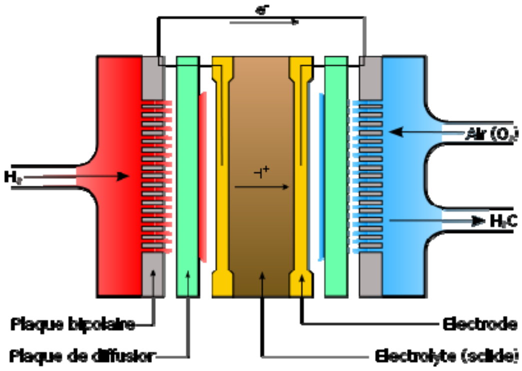

FIG. 1 OPERATION OF A FUEL CELL.

Types of Cells

A variety of fuel cells is in different stages of development. The most common classification is by the type of electrolyte used in the cell, which is:

- Polymer Electrolyte Fuel Cells (PEFC)
- Alkaline Fuel Cell (AFC).
- Phosphoric Acid Fuel Cells (PAFC) Phosphoric Acid Fuel Cell.
- Molten Carbonate Fuel Cell (MCFC).
- Solid Oxide Fuel Cell (SOFC).

In general terms, the type of electrolyte will determine the operating parameters of the cell, like the temperature range of operation of the fuel cell or the fuel temperature (Fuel Cell handbook, 2004).

Polymer Electrolite Fuel Cell (PEFC)

The electrolyte in the fuel cell is an ion exchange membrane (fluorinated sulfonic acid polymer or other similar polymers) which is an excellent proton conductor. The only liquid in the fuel cell is water, so corrosion problems are minimal. Carbon and electrocatalyst platinum electrodes are used for both the anode and the cathode. The supply of water in the membrane is critical to efficient performance. The fuel cell must operate under conditions in which water does not evaporate faster than it is produced, because the membrane must be hydrated at all times. Due to this limitation imposed by the operating conditions of the polymer, the working temperature must not in any case exceed 100°C, being the characteristic margin of this cell temperature 60-80°C. The hydrogen used should be of high purity because the anode is contaminated with traces of CO, sulfur and halogens.

PEFC cells are used for a variety of applications, but especially as a primary fuel source in hydrogen fuel cell vehicles (FCV). Because of this great interest, the development of this technology in the last decade has been extraordinary.

1) Advantages

PEFC cells have a solid electrolyte that provides excellent crossover resistance to H_2. The low operating temperature allows rapid start-up and the absence of corrosive substances which shorten the life of the cell. They are capable of achieving high current densities of more than 2 W/cm². PEFC cells are ideal to use pure hydrogen as fuel.

2) Disadvantages

The low operating temperature makes temperature control difficult, especially at high current densities. It is also difficult to use the waste heat for cogeneration or combined cycle. Controlling water is another major challenge in the design of PEFC cells because the electrolyte should moisturize without flooding it.

PEFC cells are quite sensitive to contamination by CO sulfur and ammonia. In a way, some of these disadvantages can be minimized or even eliminated by reducing the operating current density and increasing the catalyst loading on the electrode, although this leads to increased system costs.

Alkaline Fuel Cell (AFC)

The electrolyte in the fuel cell is formed by KOH; in cells which operate at temperatures of ~ 450° C the concentration is 85 wt%. For cells operating below 120°C KOH concentration is 35-50 wt%. The electrolyte is retained in a matrix; and a wide range of electro-catalysts such as Ni, Ag, metal oxides and noble metals can be used. The fuel must be pure, since if it contains CO or CO_2 it reacts with KOH to form potassium carbonate K_2CO_3, contaminating the electrolyte, thus the cell performance is greatly diminished.

The AFC was one of the first fuel cells developed from 1960. The need arose to providing power aboard spacecraft Apollo project. Although it has great success in space missions, the application uses on

Earth are less popular due to the sensitivity to CO_2. Yet, developments have been achieved with closed circuit oxygen (O_2) for mobile applications, in research carried out in USA and Europe.

1) Advantages

The AFC showed an excellent performance includes hydrogen and oxygen as compared to other fuel cells. Furthermore, these fuell cells showed a great flexibility to use a wide range of electro-catalysts

2) Disadvantages

Electrolyte sensitivity to CO_2 requires the use of highly pure H_2 as fuel and, as a consequence, the use of a highly effective reformer to remove the CO and CO_2 is also needed. Furthermore, if the ambient air is used as the oxidant, the CO_2 from the air must be removed. Although these features are not technically complicated, operation has a significant impact on the size and cost.

Phosphoric Acid Fuel Cell (PAFC)

The electrolyte used is concentrated phosphoric acid at 100%, and the operating temperature is 150-220°C. At lower temperatures, phosphoric acid is a poor ionic conductor and contamination by CO in the Pt electro-catalyst is serious.

The relative stability of concentrated phosphoric acid is high compared to other common acids, such that PAFC cells are able to work at the upper end temperature of (100-220°C). Moreover, the use of concentrated acid reduces the water pressure in the cell and the water control is easy. The most commonly used matrix to retain the acid is silicon carbide (SiC) and the electro-catalyst, both the anode and cathode, is Pt. Finally, its development has slowed in favor of the PEFC because these have a better potential for cost.

3) Advantages

These cells are much less sensitive to CO than other cells. The operating temperature is sufficiently low, so that the construction materials are not specific. It also provides a great flexibility in design for thermal control.

Efficiencies of 37-42% have been proved and waste heat can be easily used for cogeneration applications and combined cycles.

4) Disadvantages

Oxygen reduction at the cathode is slower than that in other cells and requires the use of a platinum catalyst. These cells requires fuel processing. The high phosphoric acid corrosive power requires the use of expensive materials (especially graphite plate).

Molten Carbonate Fuel Cell (MCFC)

The electrolyte in the fuel cell is usually a combination of alkali metal carbonates retained in a ceramic matrix of lithium aluminate LiAlO2. The operating temperature of the cell is 600-700°C. At these temperatures, the alkali carbonates form a highly conductive molten salt with carbonate ions which provide the ionic conduction. Operating temperatures as high nickel Ni (anode) and Nickel oxide Ni2O3 (cathode) are suitable to promote reaction without noble metals as catalysts.

The focus of development of this technology has been in stationary and sea applications, where startup time is not a problem.

5) Advantages

The operating temperature (650°C) has the advantage that electrodes do not need expensive catalysts. Waste heat from high temperature allows the use of a combined cycle, which further increases the performance.

6) Disadvantages

The electrolyte is highly corrosive and requires the use of nickel and high-grade stainless steel and manufacturing materials of the cell. High temperatures have the disadvantage of affecting the mechanical stability and shorten the life of the cell.

A CO_2 source is required at the cathode for the purpose of recycling the anode exhaust gas and thus forming the carbonate ion. The high contact resistance and resistance limited cathode current densities around 100-200 mW/cm^2.

Solid Oxide Fuel Cell (SOFC)

The electrolyte in the fuel cell is a solid non-porous metal oxide, usually yttrium oxide and zirconium oxide Y_2O_3 stabilized ZrO_2. The operating temperature of the cell is of 600-1000°C. The anode is made of Co-Ni-ZrO_2 or ZrO_2 (ceramic metal) and the cathode is Sr-doped perovskites $LaMnO_2$. In the early years of this technology, the conductivity was limited and required operation around 1000°C, but at present, cathodes have been improved and temperature was reduced to

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650-850°C. Works are still carried out to reduce the temperature in order to lower operating levels.

At present, the SOFC is used in a wide range of applications such as stationary power, vehicle auxiliary power, energy and other special applications.

1) *Advantages*

It is the fuel cell, with the longest continuous period development, since the 50s. Since the electrolyte is solid, the morphology of the cell can be of various shapes, such as tubular, flat or monolithic. Solid ceramic construction of the unit cell alleviates the problems of corrosion in the cell.

The solid electrolyte also prevents movement or flooding the electrodes. The materials used are the modest, as far as cost is concerned. As in other cells, where the operating temperature is high, it allows the use of the waste heat for cogeneration and combined cycle, increasing the output, which is now about 40 and 50%.

2) *Disdvantages*

The high temperature operation puts a limit on manufacturing processes. Materials are metallized ceramic (cermet), hard to work. Corrosion of the cell components, both in materials and connections is high, and involves an improvement in technology. These factors limit the power density and life of the cell.

Fuel Cell Future Applications

As it was commented before, fuel cells have simple design, high reliability and noiseless operation (Mekhilef et al., 2012). At the same time, nowadays buildings represent 32% of total final energy consumption. In terms of primary energy consumption, buildings represent around 40% in most IEA countries (2013). On the other hand, Transport represents 20% of global energy consumption.

As a consequence of this so high energy consumption and related Gree House Gas Emisions (GHG), new application areas are investigated in different engineering research areas like air conditioning and conservation (Kin et al., 2009; Darwish M.A., 2007). In particular, transport industry has shown a lot of future applications in scooters (Hwang J.J., 2012) and aviation (Peters and Samsun, 2013).

When scooters were evaluated, its technical feasibility was proved and a clear reduction in Green House Gases was expected when the petrol scooters were replaced. On the other hand, its applications in avionic showed a much simpler heat and water management than the other systems considered.

Another interesting conclusion is the effect of temperature over its efficiency. In particular, it was obtained that desert areas, under a hot and dry environment, its efficiency will be clearly reduced.

Finally, there is not too much information about the application of the fuel cell to green house effect reduction by means of isolated small power plants of air conditioning reaching the power output needed for average as well as peak A/C system capacity. Furthermore, research works about the application of fuel cells in vehicles for air conditioning systems have been carried out.

Despite this fact, different reviews (Kirubakaran et al., 2009) showed the lack of a research area about conservation of plants during their transport. This interesting point of view has not been anlaysed before despite the fact that its future applications could be the key of gas emission reduction in transport. In consequence, this research line must be analysed in depth in future research works.

Conclusions

In the present research work, different fuel cells were analysed and classified and their main advantages and disadvantages were highlighted. Furthermore, a review of the most important advances in fuel cell applications showed to be exactly the same in the most important world energy consumption areas.

In particular, conservation and transport atmospheres in the agroforestry industry and future derived works like new electrical vehicles or plant conservation in greenhouses have been proposed.

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